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Growing Ornamental Greenhouse Crops in Gravel Culture

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GROWING ORNAMENTAL GREENHOUSE CROPS IN GRAVEL CULTURE

ALEX LAURIE AND D. C. KIPLINGER

INTRODUCTION

The term "gravel culture" is generic in nature and applies to the growing of plants without soil in an inert medium into which nutrient solutions are usually pumped automatically at regular intervals. Haydite (shale and clay fused at high temperatures), soft- or hard-coal cinders, limestone chips, calcareous gravel, silica gravel, trap rock, crushed granite, and other inert and slowly decomposing materials are included in the term "gravel."

As a laboratory technique, growing plants without soil in nutrient solutions dates back to the middle of the nineteenth century, to the original work of Bousingault, Liebig, Salm-Horstmar, and Sachs, who provided the mineral nutrition theory of today. Their techniques were elaborated and improved by such workers as Knop, Tollers, Pfeffer, Tottingham, Shive, Hoagland, and others.

The first practical application of growing plants without soil was made by Pember and Adams (11), who attempted to grow carnations in sand to determine their nutritional needs. Biekart and Connors (2) in 1927 succeeded in developing a satisfactory method of growing carnations in sand which was surface-flushed regularly with nutrient solutions. Laurie (8, 9) and his assistants were likewise engaged about the same time in growing different flowering crops in sand with additions of nutrients in dry form. Gericke (6) was one of the first to advocate the commercial use of water culture, the growing of plants with their roots constantly immersed in a nutrient solution.

Automatic subirrigation received its impetus from the work of Eaton (5), who demonstrated that solutions supplied automatically from below to sand saved much labor and were quite satisfactory. Withrow and Biebel (15) developed the original mechanics in 1936, and a little later a somewhat similar arrangement was introduced by Connors and Tiedjens (3). In 1937, workers at the Ohio Agricultural Experiment Station (10) began using the same method, following the mechanical setup of Withrow and Biebel. In place of sand, coarse aggregates were substituted.

The reasons for the attempts to apply such methods to the practical culture of crops in the greenhouse are several. Since soil is a complex medium, absolute control of nutrition is difficult, and even the most expert growers have crop failures frequently. The automatic subirrigation method with solutions supplied to plants growing in an inert medium provides an exact and uniform system of procedure with ease of modification to conform to environmental variations. The labor saved by such a procedure is likewise to be considered, as well as the continued use of the medium selected without the frequent changes necessary when soil is used. Further advantages lie in the greater uniformity of quality of the crops so produced and the possibility of higher production due to optimum growth conditions. It must be understood, however, that if perfection of growth is attained in soil, just as good quality and as high a production can be expected in soil as in soilless culture.

The work that was started in 1937 at the Ohio Agricultural Experiment Station has gradually progressed, and a considerable area of the greenhouse space is now devoted to soilless culture. A large variety of crops has been grown successfully, and many of the initial difficulties have been overcome, so that it is now safe to make specific recommendations with the expectation of success, provided these are followed exactly. Many commercial establishments have likewise tested this procedure, at first on a small scale, later gradually enlarging to devote considerable space to the growing of crops commercially without soil.

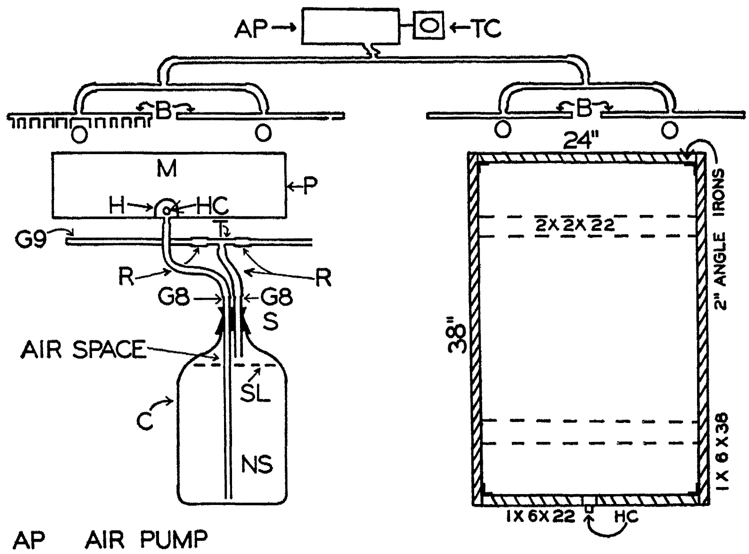
Because many small plots were needed to secure the required experimental data for this work, inexpensive units were devised by several graduate assistants (Arnold Wagner, Joseph Fueglein, Raymond Hasek, and D. C. Kiplinger) of the Ohio Agricultural Experiment Station and located at Columbus.

SMALL EXPERIMENTAL PLOTS

In figure 1 is diagramed the assembly of a unit containing a number of small plots. AP is an air pump controlled by a time clock TC. B is a bleeder made by placing a pinch clamp over a piece of ¼-inch by 5/64-inch rubber tubing, almost closing the aperture. A small valve similar to those used in laboratories on Bunsen burners connected at the end of the main line G9 will serve as a bleeder as pressure is released through the valve. O stands for air outlets for carboys, and the diagram illustrates how 40 plots can be operated simultaneously. P is the 2-foot by 3-foot by 6-inch experimental plot. H is the half-tile, M the medium to be used, and HC a male hose connection screwed into the front board. R is ¼-inch by 5/64-inch laboratory rubber tubing cut long enough to allow for complete removal of the rubber stopper and glass tubing from the carboy for additions of water and nutrients. G9 is 9-millimeter glass tubing which is the main air line that issues from a pump. T is a 9-millimeter glass tee connected by ¼-inch by 5/64-inch rubber tubing R to the main air line. G8 is 8-millimeter glass tubing. The short piece does not extend into the solution, but the long piece extends to one-half inch from the bottom of the 5-gallon carboy C. S is a No. 6 two-holed rubber stopper which must fit tightly enough in the neck of the carboy to prevent escape of air. SL is the level of the nutrient solution NS maintained in the 5-gallon carboy. The solution level SL should be maintained at the point illustrated in figure 1, as some air space is necessary to keep the nutrient solution from backing up into the main air line; furthermore, the volume of solution in the carboy at this point is just sufficient to fill the 2-foot by 3-foot by 6-inch plot within 1 inch of the top. Pumping to this level prevents algae growth on the surface of the medium.

An inexpensive pump and motor manufactured for paint spraying are adaptable for use as a source of compressed air. When the motor is in operation, compressed air is pumped through G9 and pressure is built up in the air space above the solution level SL. This pressure forces the nutrient solution into the long piece of G8 glass tubing leading to the plot P and thereby fills the plot. A time switch is a convenient device for regulating the period necessary to empty completely the carboy C. Some pumps are so constructed that air will leak back through them, thus dissipating the pressure. No bleeders are necessary with such pumps, as the solution will drain back by gravity into the carboy.

As many as 40 small plots can be operated successfully with a paint sprayer motor and pump. About 8 minutes are required for pumping and 20 minutes for complete drainage of 40 plots operated simultaneously. If the pump is connected at the end of the series of 40 plots, uniform pumping will not be obtained. Those nearest the pump will empty first, releasing the pressure so that the remaining partially pumped plots will begin to drain immediately. In order to obtain uniform pumping of 40 plots, it is necessary to assemble the main air line as diagramed at the top of figure 1.



AP	AIR PUMP
TC	TIME CLOCK
B	BLEEDER
O	OUTLETS FOR CARBOYS
M	MEDIUM
P	EXPERIMENTAL PLOT 2' X 3' X 6"
H	HALF TILE
HC	MALE HOSE CONNECTION
T	NINE MM. GLASS T
G9	NINE MM. GLASS TUBING
G8	EIGHT MM. GLASS TUBING
R	1/4" X 5/64" RUBBER TUBING
S	NO.6 TWO HOLED RUBBER STOPPER
SL	SOLUTION LEVEL
C	FIVE GALLON CARBOY
NS	NUTRIENT SOLUTION

Fig. 1.—Diagram of a small plot assembly

All air lines are assembled from 9-millimeter glass tubing, 9-millimeter glass tee tubes, and ¼-inch by 5/64-inch rubber tubing. Bleeders are similar to those previously described. By diverting the air so that each series of 10 plots receives approximately the same pressure, pumping is made uniform. By trial-and-error methods it is possible to balance the pressure in the main air line so that plots in various sections of experimental greenhouses can be used, as is often necessary under various light, temperature, and other environmental conditions.

The construction of plots small enough to be filled from a 5-gallon carboy is diagramed to the right in figure 1.

The bottom of the plot is constructed by placing two pieces of 1-inch by 12-inch by 38-inch lumber side by side and nailing them to the two pieces of 2-inch by 2-inch by 22-inch lumber indicated by the dotted lines. These 2-inch by 2-inch by 22-inch pieces prevent sagging of the bottom when the plot is filled with medium. The sides are then cut to fit on top of the bottom of the plots. At this time a hole should be bored in the board that will be the front of the plot. The hole should be located flush with the bottom of the plot to allow for complete drainage of the plot after pumping. This hole is to accommodate the male hose coupling and should be slightly smaller than the diameter of the coupling to ensure a tight fit. The hose coupling should fit into a ¼-inch or ⅜-inch hose to allow for ease of removal of the rubber tubing.

The sides are then nailed onto the plot bottom and to each other at the end. The 2-inch by 2-inch by 22-inch pieces should be underneath, not within the plot. Then the 2-inch angle braces should be screwed inside at each corner about 4 inches up from the bottom to prevent the boards from pulling apart when the plot is filled with medium. The plot is then waterproofed on the inside only with asphalt emulsion or any similar substance not toxic to plants. Sometimes it is difficult to waterproof the plots completely because of warped boards. Strips of laboratory cheesecloth are laid on top of the wet asphalt emulsion at all points and are thoroughly impregnated by the application of additional emulsion. Two coats are usually sufficient. When the cheesecloth is placed behind the angle irons before they are permanently screwed in place, a greater margin of safety that the corners will remain waterproofed is secured.

A container of similar dimensions constructed of reinforced concrete with provisions for drainage is more satisfactory than a wooden container. Leaks occur less frequently, and there is no danger that the sides will separate from each other or the bottom when the plot is filled with medium.

Before the assembled plots are filled with medium, the half-tile is placed on the bottom of the plot directly in line with the hose connection. An asphalted eaves trough may be substituted, but zinc toxicity is often encountered when the asphalt deteriorates. The purpose of the tile is to allow the solution to spread uniformly and quickly throughout all parts of the plot and to prevent the entrance of medium into the rubber tubing. The use of black iron window screen is advised at the joints and end of the tile. The tile should not fit perfectly on the bottom of the plot, because entrance and exit of the solution will be hindered. Pieces of wooden plant labels placed under the tile eliminate this difficulty.

After the equipment has been assembled, the plot is filled with medium and connected to the 5-gallon carboy. It is essential that the plots be tilted slightly toward the front to permit free drainage, as solution standing on the bottom of the plot seems to inhibit plant growth.

When all installations have been made correctly, the successful operation of many plots depends on two factors: balance of air pressure, and maintenance of proper water levels. The complete pumping of some plots while others are only partially pumped will result in a release of air pressure and immediate drainage of all plots.

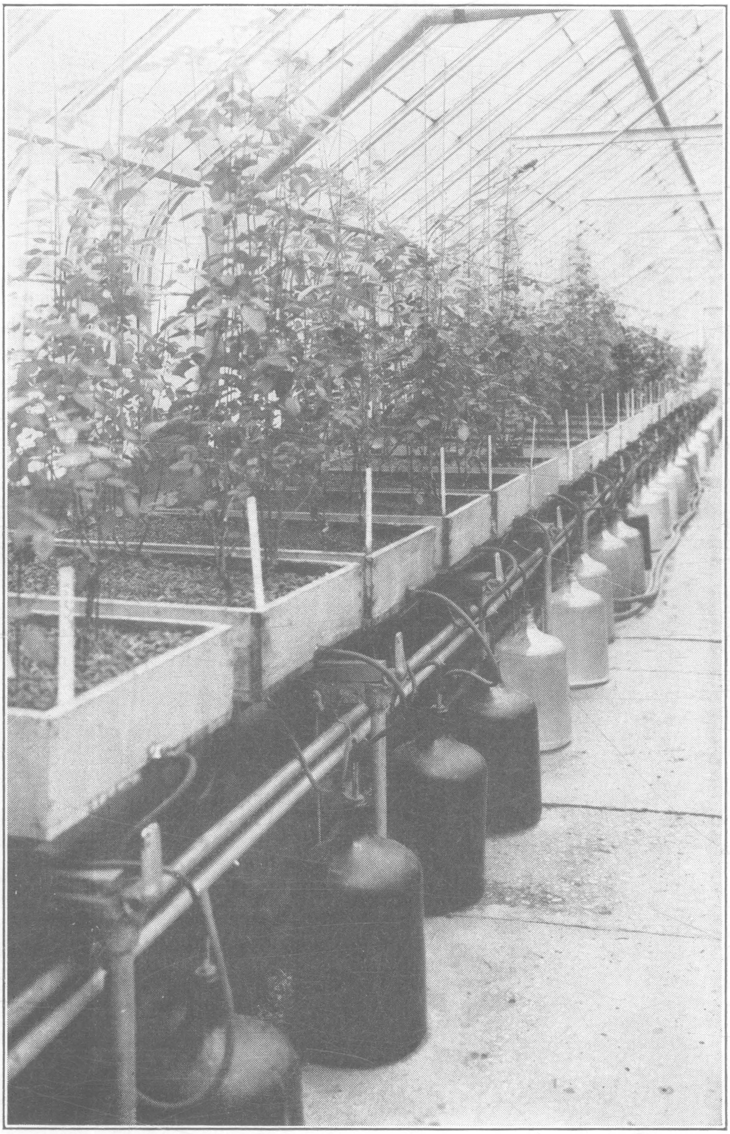


Fig. 2.—Numerous small plots can be operated successfully with an air compressor.

EQUIPMENT

BENCHES

The most satisfactory bench for growing crops in inert media is made of concrete with a V bottom. The bench should slope 1 inch to 100 feet, although when an auxiliary pipe is used for inlets and outlets, no slope at all is needed, since the pipe can be slanted to suit the needs of good drainage. The sides of the bench may be 6 to 8 inches high and the bottom so shaped as to have a slope of 1½ inches from the sides to the center to make the V. If flat-bottomed concrete benches have already been built, they can be converted to gravel culture by the following method: A form should be made as shown in figure 3 to fit within the bench. The inside of the bench should be covered with emulsified asphalt to prevent the old concrete from binding with the new, and if drainage holes are large, they should be covered with old cheesecloth and asphalt. A dry concrete mix should be prepared from a one to four mixture of cement and AAA Haydite or sand. This mixture is placed in the bench and tamped roughly into the form of the modified V. To finish the V in the bench, the form (fig. 3) should be pushed down into the wet concrete and moved back and forth. The concrete should be smoothed with a metal trowel. To minimize the amount of water in the bottom of the V, a short length of 1-inch pipe should be rolled back and forth in the V to form a notch or small depression. The water that will stand then will be in the depression under the tile, and no damage will result. A layer of concrete at least one-half inch thick should be retained between the bottom of the V notch in the V and the top surface of the old bench, to prevent cracking of the new concrete (fig. 4).

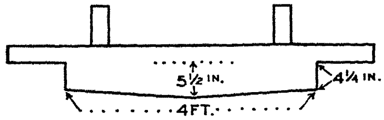


Fig. 3.—Form used to convert existing flat-bottomed wooden or concrete benches into a modified V bottom

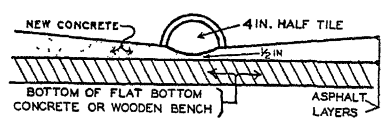


Fig. 4.—Detail of bottom of a modified V-bottom bench showing notch under the half-tile into which the solution finally drains

Wooden benches with bottom boards running across the bench can be converted by placing additional supports under the bench to prevent sagging. The inside of the bench should be cleaned and the sideboards made level. The same procedure as outlined for the flat-bottomed concrete bench should be followed. Benches with bottom boards running lengthwise will sag unless heavy supports are placed between the bench legs. A wooden V can be made as shown in figure 5. For an all-wood bench, the joints must fit perfectly and the supports be rigid.

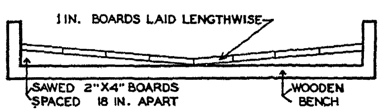


Fig. 5.—Construction detail of an all-wood bench

Both concrete and wooden benches should be coated inside with a watery dressing of asphalt emulsion and then covered again with a thicker coating. As soon as dry, the benches should be filled with water and tested for leaks. If any develop, a patch of cheesecloth covered with asphalt usually corrects the trouble. A cheap grade of emulsified asphalt, such as is used for road building is satisfactory, provided it contains no oil or tar. One gallon of undiluted asphalt emulsion will cover about 50 square feet of surface.

TANKS

In order to provide suitable containers for the nutrient solutions, tanks are installed under benches or in other suitable locations. Such tanks have several requisites. They must be waterproof, acid resistant, and of sufficient size to hold about 40 per cent of the total volume of the benches that they fill. These tanks can be made of concrete, wood, or metal. For small installations, milk vats or even grave vaults have been used. All tanks made of concrete should be coated with sodium silicate diluted one part to four of water, emulsified asphalt, or both. Wooden and metal tanks should be coated with asphalt and made absolutely acidproof. It has been suggested that tanks should contain enough solution to equal the total volume of the benches instead of the 40 per cent recommended here. Although true that a larger volume of solution makes it easier to maintain the proper levels of nutrients, the additional costs of construction are so high as to make such recommendations impractical. For benches over 100 feet long, tanks can be placed in the middle of the house so that the bench drains from each end to the center, or else the tanks can be placed at the end of the greenhouse and the benches sloped toward them.

INLET PIPES

Black iron pipe, not galvanized, should be used for the inlets. For a 100-foot bench, one inlet of 1- or 1½-inch pipe near the pump at the end of the bench is sufficient, although better drainage can be provided by the placing of a separate pipe under the bench or alongside. The size will depend on the length

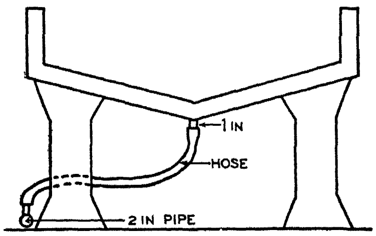


Fig. 6.—Pipe for extra inlets placed alongside the bench instead of underneath

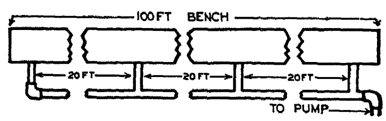


Fig. 7.—Lengthwise view of 100-foot bench with placement of extra inlets

of the bench. For small installations, 1½-inch pipe will suffice. Proportionally larger sizes are needed for long benches (fig. 6 and 7). The inlet into the bench should be flush with the bottom of the V and completely waterproofed, since it is frequently the source of leaks.

VALVES

Figure 8 indicates the method of manipulating valves when spraying is done and solutions are changed. In the upper diagram of figure 8, for normal operation, valve 1 should be open and valve 2 should be closed. To pump out the tank, valve 1 should be closed and valve 2 opened. To flood the bench prior to spraying, valve 1 should be closed. To drain water from the bench after spraying, the cap on the pipe projecting from the end of the bench should be

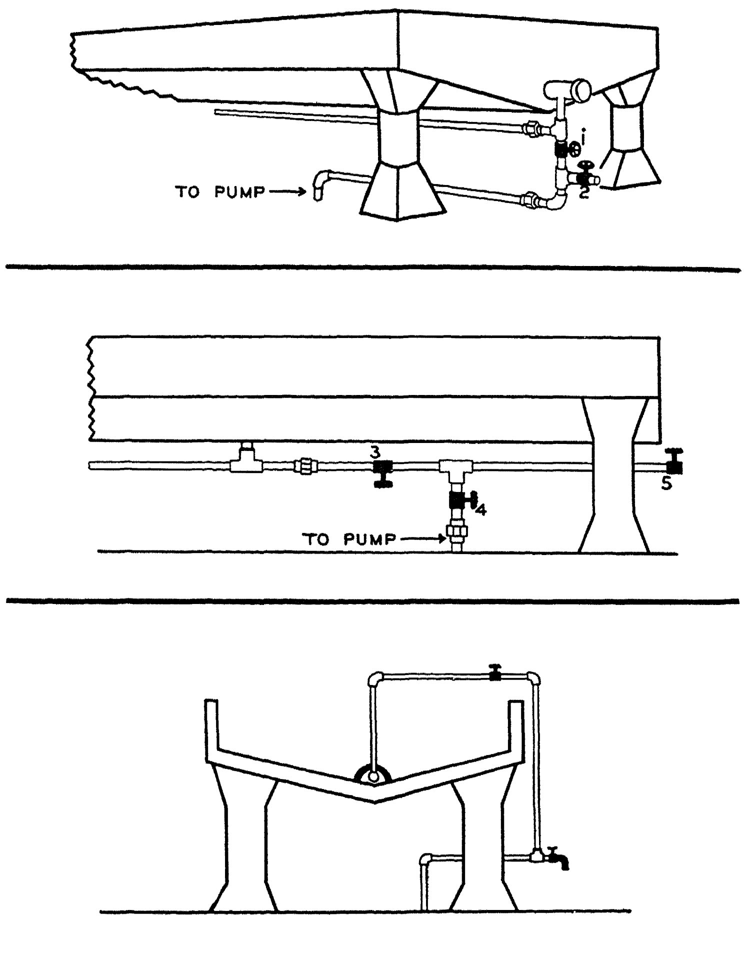


Fig. 8.—Upper section—Bench construction and valve arrangement with inlet located at end of the bench

Middle section—Bench construction and valve arrangement with inlet located under the bench

Lower section—Cross section of V-bottom bench showing half-tile and pipe arrangement for flooding bench prior to spraying

removed. In the central diagram of figure 8, for normal operation, valves 3 and 4 should be opened and valve 5 closed. To pump out the tank, valve 3 should be closed and valves 4 and 5 opened. To flood the bench prior to spraying, valve 3 should be open and valves 4 and 5 closed. To drain water from the bench after spraying, valve 5 should be open.

TROUGH

To obtain rapid spread of the solution in the bench, any one of the following suggested methods is satisfactory: half-tile (fig. 9), eaves troughs with beads removed, or a wooden inverted V. The eaves trough should be asphalted to prevent zinc damage, and wedges should be placed between it and the bench bottom to allow for entrance and exit of the solution. Large cracks or openings should be covered with black iron screen to prevent the medium from clogging the trough.

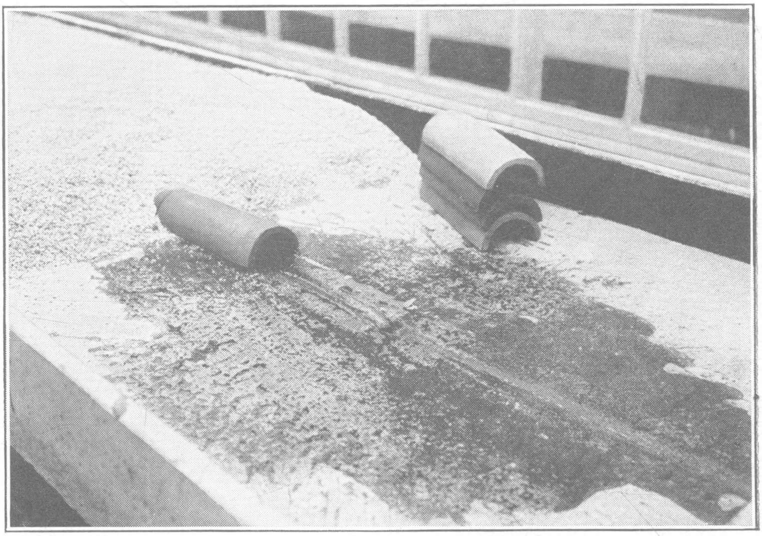


Fig. 9.—Half-tile used as a solution channel. Note the inlet from below the bench in the center of the picture and the notch at the bottom of the concrete in this modified V-bottom bench.

PUMPS

Either a sump or side-suction centrifugal pump can be used for flooding the bench. Sump pumps are easier to install, since a separate compartment is unnecessary in the tank to keep the motor dry.

The quicker the pumping and drainage are completed, the better the results. Benches should be filled in at least 30 minutes and should drain in 60 minutes. The following pumps have been used in tests and found satisfactory:

Deming No. 4000-M—No. 1 Side Suction Centrifugal Pump. When ordering, specify that a grease cup be supplied rather than the water-lubricated mechanism at the main bearing. Capacity 30 gallons per minute, 10-foot head. Deming Company, Salem, Ohio.

Deming No. 4602—Sump Pump. Capacity 40 gallons per minute, 10-foot head.

Gould "Cid" Sump Pump—No. 3151. Gould's Pumps, Inc., Seneca Falls, New York.

Myers No. 6101 Sump Pump. Capacity 25 gallons per minute, 10-foot head. F. E. Myers & Bro. Co., Ashland, Ohio.

Other manufacturers make pumps that are just as suitable. Allow at least 6 inches from the surface of the solution to the electrical box on all sump pumps for slopping of the solution when agitated.

TIME CLOCKS

Electric clocks (fig. 10) ensure regular pumpings. The present empirical recommendations of so many times per day serve the purpose. The following types are available:

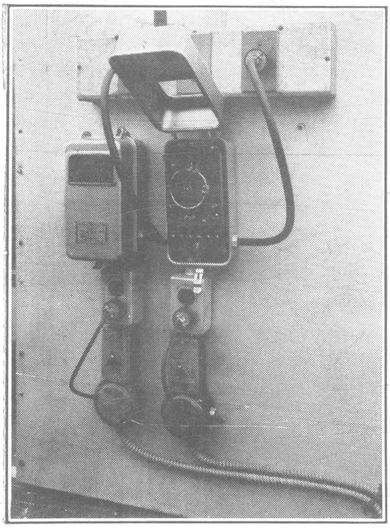


Fig. 10.—Time clocks used for automatic control of the number of pumpings per day

Type T-27 Time Switch, Single Pole, Single Throw, General Electric Co., Schenectady, New York. Specify whether 115 V or 230 V clock is desired. Any number of additional "on" and "off" tabs can be secured.

Type K-11 Sangamo Time Switch, Sangamo Electric Co., Springfield, Illinois, is satisfactory if a maximum of three pumpings per day is desired.

MEDIA

The most satisfactory material for the growth of plants with the subirrigation method is one that is inert, does not give off any undesirable elements, does not change the pH, retains a sufficiency of water, and does not disintegrate. To date, there is nothing that approximates this ideal as closely as Haydite. Where trap rock, granite chips, or silica gravel (acid) are available, they serve the purpose as well as Haydite. The C grade of Haydite, composed of a mixture of coarse (three-fourths inch diameter) and fine particles is the most suitable size, although it has been found that finer sizes may be more suitable, particularly when inadequate drainage is provided. Because of the coarseness of the medium, there is a tendency for the roots to form at the bottom of the bench instead of throughout the entire body of the medium. This condition is probably due to excess aeration. The formation of the entire root system at the bottom necessitates complete drainage, else damage may occur to the roots even though a very small amount of solution remains standing (fig. 11 and 12). In finer media, root development occurs over a greater territory and standing solution at the bottom may not cause serious damage.

Hard- and soft-coal cinders may likewise be used, although statements about their cheapness should be tempered, since screening and leaching consume time and labor. Cinders vary with the source of coal and in some localities may contain toxic substances. Excess of boron has been found in some localities and if present can be neutralized by the addition of 10 cubic centimeters of commercial sodium silicate to 100 gallons of solution. This addition may be made even after the plants are benched. Some cinders disintegrate readily and may be troublesome because of high water-holding capacity and insufficient aeration. Occasionally cinders are alkaline and may precipitate iron, phosphorus, and manganese. As a precautionary measure, cinders should be leached thoroughly. One-fourth to three-fourths of an inch are suitable sizes for cinder particles.

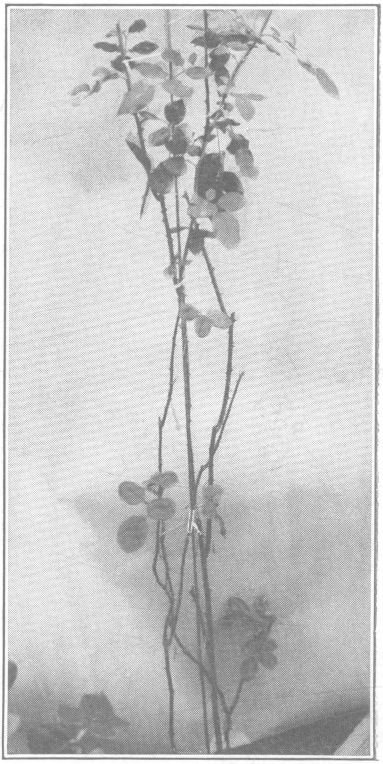


Fig. 11.—A Joanna Hill rose grown in a flat-bottomed bench where water was standing. Note extreme defoliation and chlorosis of leaves near the top of the photograph.

Calcareous gravels are suitable for crops that grow satisfactorily in a pH of 7 or above. As a consequence of the high pH, precipitation frequently occurs. When these gravels are used, a precaution recommended is the broadcasting of monocalcium phosphate at the rate of 5 pounds to 100 square feet before planting. This material should be watered in thoroughly. Apparently after a period of time, a coating of phosphorus over the gravel particles minimizes the initial difficulties with high pH. Calcareous gravels are particularly unsuitable for roses and gardenias. Particles one-fourth to one-half inch in size are best.

Limestone chips can be used in a manner similar to calcareous (lime-bearing) gravel. Slag from blast furnaces should be avoided because of its extreme alkalinity and possible toxic content.

SOLUTIONS

The nutrient elements are supplied to plants in solution form.

Many different formulas have been advocated by various workers. The differences between them are not very great, but to save confusion, we present the solution which has proved satisfactory on many crops.

Fig. 12.—Standing water in a flat-bottomed bench—an undesirable environment for optimum plant growth

COMPOSITION OF THE WP* FORMULA

Chemicals	Per 1,000 gal. of water
Potassium nitrate	5 lb. 13 oz.
Ammonium sulfate	.... 15.5 oz.
Magnesium sulfate	4 lb. 8 oz.
Monocalcium phosphate	2 lb. 6.5 oz.
Calcium sulfate	10 lb. 12 oz.
Total	24 lb. 7 oz.

*Developed by Arnold Wagner and G. H. Poesch of the Horticulture Department of the Ohio Agricultural Experiment Station.

The chemicals given in the formula should be mixed together in dry form. The mixture will not deteriorate and can be stored and used as needed.

Because of the present difficulty of securing the commercial grade of potassium nitrate, the following modification of the WP formula is suggested:

Chemicals	Per 1,000 gal. of water
Calcium nitrate or sodium nitrate	5 lb.
Potassium chloride	5 lb.
Ammonium sulfate	1 lb.
Magnesium sulfate	4.5 lb.
Monocalcium phosphate	2.5 lb.
Calcium sulfate	5 lb.

The chemicals in this latter formula should be weighed out individually and mixed in the tank.

A single-strength WP solution should be used for the first month on all newly planted crops. When the plants have become well established, usually after 3 to 6 weeks, the concentration should be doubled, or twice the amount of chemicals per 1,000 gallons of water recommended in the WP solution should be used.

Manganous sulfate should be added to all solutions each month. One ounce of manganous sulfate is dissolved in 1 gallon of water acidified with three to five drops of commercial sulfuric acid. All this solution should be used for 1,000 gallons of nutrient solution. Iron should be added weekly in the form of ferrous sulfate at the rate of 4 ounces per 1,000 gallons.

SOURCES OF CHEMICALS

The chemicals used are of commercial grade and are reasonably priced.

Commercial potassium nitrate is difficult to obtain and for the present should be eliminated from consideration. Calcium nitrate can be obtained from the Synthetic Nitrogen Products Corporation, New York, New York.

Monocalcium phosphate can be obtained from the Monsanto Chemical Company, St. Louis, Missouri, Akron, Cleveland, or Cincinnati, Ohio. The reason for the use of this food-grade material is its low fluorine content. The fluorine may not be as dangerous as originally thought, however, and treble phosphate has been used satisfactorily.

Sodium nitrate, potassium chloride, ammonium sulfate, calcium sulfate, magnesium sulfate, and ferrous sulfate can be obtained from local dealers. Since only small amounts of manganous sulfate are necessary, they can be obtained from a druggist.

Since the materials used are not chemically pure, they contain the necessary trace elements without additions except those mentioned. Recommendations for adding boron, zinc, copper, and other elements should not be followed without specific advice. Considerable damage has resulted in some cases because of overzealousness. The addition of small amounts of thiourea, tryptophane, liquid manure, indolebutyric acid, sugar, nicotinic acid, or vitamin B_1 has not proved beneficial.

CHANGING SOLUTIONS

The original recommendation called for a change of solutions weekly, but at present no complete change is necessary more frequently than once in 2 months. In some instances, solutions have not been changed for several months, but as a precautionary measure, a change every 2 months is advocated.

TESTING SOLUTIONS

The Simplex Soil Testing Kit or the LaMotte Soil Testing Kit can be used for general purposes. The Simplex is sold by the Edwards Laboratory, Lansing, Michigan, the LaMotte by the LaMotte Chemical Co., Baltimore, Maryland. For accurate tests for nitrogen, the phenol disulfonic acid method is used.

The analysis of a WP and 2 WP solution is given in table 1. The differences between the nutrient levels of the calculated and fresh solutions are accounted for by precipitation of the nutrients, low solubilities, or inaccuracies of the present quick tests.

TABLE 1.—Analysis of nutrient solutions in parts per million

	WP		2 WP	
	Calculated	Fresh solution	Calculated	Fresh solution
Nitrates	400	400	800	750
Ammonium	28	25	56	50
Phosphorus	65	60	130	120
Potassium	250	250	500	500
Calcium	310	150	620	250

Since phosphorus may readily precipitate from the solution or be absorbed by the plant, tests and additions should be made weekly. Nitrate and potassium tests made every other week after changing are sufficient. It is not necessary to test for magnesium unless solutions are infrequently changed. Addition of the full amount of magnesium sulfate every 2 months is advocated. The nutrient levels given in table 2 can be maintained with satisfactory results:

TABLE 2.—Nutrient levels in parts per million

	WP	2 WP
Nitrates	400	600 plus
Ammonium	25	50
Phosphorus	25	40
Potassium	100	200
Calcium	125	200

After the solution is tested, it is necessary to make additions of the deficient nutrients. The amounts of chemicals per 1,000 gallons of water to provide definite parts per million are as follows:

5 pounds of calcium nitrate provide 130 parts per million of calcium and 400 parts per million of nitrates.

5 pounds of potassium chloride provide 250 parts per million of potassium.

5 pounds, 13 ounces of potassium nitrate provide 250 parts per million of potassium and 400 parts per million of nitrates.

1 pound of ammonium sulfate provides 28 parts per million of ammonium.

4½ pounds of magnesium sulfate provide 50 parts per million of magnesium

2½ pounds of monocalcium phosphate provide 65 parts per million of phosphorus (200 parts per million of phosphate).

5 pounds of calcium sulfate provide 145 parts per million of calcium.

During favorable growing seasons for the various crops, the full amount of ammonium sulfate is sometimes added every other week, but since the ammonium is quickly converted to nitrate, this practice may develop undesirably high nitrate levels. If such levels develop, less frequent additions should be made.

The water level in the tank is fully as important as the nutrient level and should be checked daily.

pH

The pH of the solution should be checked twice a week without fail. It should be maintained at 6.5 for most crops. Gardenias do best at a pH of 5.5 to 6. Sweet peas, stocks, carnations, gerbera, feverfew, asters, pansies, chrysanthemums, and others will grow satisfactorily in a pH of 7.

To raise the pH, a stock solution of 2 ounces of sodium or potassium hydroxide to a gallon of water should be used, or ammonium hydroxide and water, one part to three, respectively, can be used. To lower the pH, a stock solution of 1 ounce of either concentrated sulfuric or phosphoric acid to a gallon of water should be used.

When any materials are added to a solution, thorough stirring is necessary to obtain proper mixing.

TIME OF PUMPING

The number of times per day the solution should be pumped depends on the type of medium, season, and size of plants. In summer, mature rose plants in a coarse (½- to 1-inch) medium should be pumped three to four times during the daylight period (7 a. m., 11 a. m., 2 p. m., 5 p. m.). In winter, pumping should be reduced to one or two times daily. Carnations should rarely be pumped more than twice daily in summer and every other day in winter, providing no wilting occurs. Young plants which are not established should be pumped less frequently, as root action is slow. Experience is the best guide, together with a close check of growth of the plants. The solution should be pumped to within 1 inch of the surface of the medium to prevent the growth of algae (green scum). Night pumping is not essential.

PLANTING

Plants can be set in the medium in a V-bottom bench with a ball of soil out of 2- to 3-inch pots. The roots spread rapidly into the inert medium, and no check in growth is observed, such as occurs when the soil is washed off. If drainage is poor, this planting practice is dangerous, especially with soft-stemmed crops, such as snapdragons and chrysanthemums, since they rot easily. The soil does not dissolve into the medium but remains intact and is removed when the plants are pulled out. Bulbs are planted so that their "noses" are one-half inch below the surface of the medium. Too deep planting results in rotting, which can be partially overcome by less frequent pumping. Plants should be spaced in gravel similarly to the way they are in soil. Large seed (sweet peas) can be sown directly in the medium.

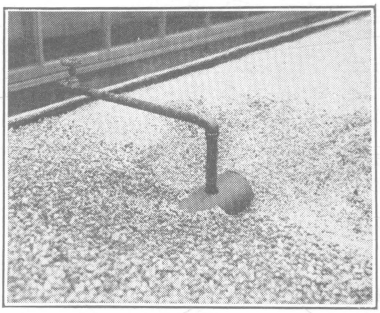


Fig. 13.—A method of flooding a bench with tap water prior to spraying

PEST CONTROL

Since the media do not contain any organic matter which would act as a buffer, any spray materials used may cause damage to the roots. To prevent such damage, the benches should be flooded with clear water prior to spraying (fig. 13). Some commercial tests show that this may not be necessary, but it is better to be sure. If the nutrient solution is to be changed, it should be pumped into the bench, the plants sprayed, and the solution discarded by manipulation of the valves as described previously. It is advantageous to run a permanent water line to the half-tile in the bench so that the bench can be flooded for spraying by opening a valve as shown in figures 8 and 13. Sulfur sprays or dusts lower the pH. Cyanide fumigation is not always safe. Nicofume fumigation is safe. For sterilization purposes, copper or mercury compounds should be avoided, as toxicity is apt to result from their use. Insects in the medium can be controlled by flooding the bench to float the insects and then spot-fumigating with nicofume pressure fumigators. Fulex (naphthalene vapor) fumigation is reported to be safe.

SPECIFIC CROPS

To test the effectiveness of growing crops in gravel, the most important greenhouse flowering crops have been grown from 1937 to the present time. They included roses, carnations, chrysanthemums, gardenias, snapdragons, sweet peas, lilies, iris, narcissi, asters, stocks, euphorbia, Boston yellow daisies, pansies, feverfew, annual chrysanthemums, calendula, dahlias, bachelor buttons, and others.

ROSES

Various solutions and media.—One of the earliest tests with roses was made to determine the effectiveness of several recommended solutions and several media. Dormant-budded "started eye" plants of Better Times roses were used in this test. They were planted in February 1938. Table 3 shows the production record for 1 year. It will be noted that soil-grown roses produced fewer flowers per plant and poorer grade flowers than those grown in silica gravel or cinders. The differences between solutions used were not significant, but the differences between cinders and the two grades of silica gravel were significant.

TABLE 3.—The production of Better Times roses in various nutrient solutions

Planted February 1938. Recorded to February 1939

Nutrient solution	Medium	Flowers per plant	Per cent by grade								
			Shorts	9 inches	12 inches	15 inches	18 inches	21 inches	24 inches	27 inches	30 inches
....	Soil..............	13.0	13	48	19	10	7	2	1	......	......
2 E*	Silica gravel......	19.5	11	33	28	17	6	5	......	......	......
2 WP*	Silica gravel......	22.0	4	20	31	22	14	6	2	....	1
2 W*	Silica gravel.....	20.0	3	14	23	25	19	9	6	......	1
2 WP	Fine silica gravel.	17.5	7	19	24	28	12	6	4	......	......
2 WP	Coarse cinders...	26.0	2	10	24	22	24	12	6	......	......

*For composition of the solution see tables 40 and 41.

Potassium additions.—Since high potassium content is usually recommended for optimum growth and production of roses, a test was made in 1939 to determine the effectiveness of potassium additions. Table 4 shows the effect of increasing the potassium content of 2 WP solution on the production of Lucile Hill rose. It will be noted that again, as in table 3, the production in gravel is higher than in soil and that an increase in the potassium content of the 2 WP solution increases the production over that in the regular 2 WP solution significantly. The WP solution ratio of nitrogen to potassium is about two to one, and it is possible that a change to approximately a one to one ratio might increase the rate of stored carbohydrate utilization during the night and result in the development of a greater number of shoots per plant.

TABLE 4.—The effect of increasing the potassium content in the nutrient solution on the production of the Lucile Hill rose

Treatment	Flowers per plant	Per cent by grade					
		Culls and shorts	9 inches	12 inches	15 inches	18 inches	21 inches
2 WP	17.0	14.7	36.3	30.4	12.7	4.9	1.0
2 WP plus 500 parts per million of potassium..................	21.3	16.4	36.7	26.6	13.3	4.7	2.3
Soil	12.8	15.8	40.8	27.9	11.7	3.3	.4

Glucose additions.—In an attempt to supply additional carbohydrates to roses during cloudy winter weather, Better Times and Happy Days roses were supplied with glucose solutions at concentrations of 1.3, 2.6, and 4.1 per cent. No differences in growth could be observed, but considerable difficulty was encountered because of increased bacterial activity at the roots and a subsequent check in growth. This activity was finally controlled by additions of silver as silver nitrate at the rate of one to two parts per million.

Trace element additions.—Some workers have recommended the additions of such trace elements as boron, copper, and zinc to nutrient solutions to secure greater growth and development of plants. Table 5 shows the results of such treatments on the Better Times rose. It will be noted that some increases in production were observed from addition of boron and zinc in low concentrations. The additions of copper proved to be detrimental. Since the materials composing the nutrient solutions are commercial in form, they frequently contain some of the trace elements; hence, under such conditions, any additions may be unnecessary and sometimes even detrimental. Certain white varieties of roses, such as Snow White and American Pride, are benefited by additions of boron up to five parts per million.

Occurrence of trace elements.—A WP solution with recommended additions of ferrous and manganous sulfates was flushed through C grade Haydite, and a 500-cubic centimeter sample was taken for spectrographic analysis. Although the relative amounts of the mineral elements present cannot be determined accurately by this method of analysis, minute quantities can be detected readily. The following minerals were found in their estimated order of decreasing concentration: calcium, potassium, magnesium, silicon, sodium, iron, aluminum, titanium, copper, manganese, and vanadium. With the presence of these trace elements in the solution, either from the fertilizer-grade chemicals or the Haydite, their addition would appear unwarranted unless a deficiency occurs.

TABLE 5.—The effect of various concentrations of boron, copper, and zinc on the production of Better Times roses

Planted January 2, 1939. Recorded to August 8, 1939

Additional treatment	Basic solution	Flowers per plant	Per cent by grade						
			Culls and shorts	9 inches	12 inches	15 inches	18 inches	21 inches	24 inches
1 part per million of boron (later 5 parts per million)...	2 WP	14.7	14.8	19.3	29.6	21.6	11.4	2.3	1.1
2 parts per million of boron (later 10 parts per million)..	2 WP	14.2	7.1	32.9	23.5	28.2	7.1	1.2	......
1 part per million of zinc (later 10 parts per million)..	2 WP	14.7	4.6	36.4	30.7	21.6	4.6	2.3	......
2 parts per million of zinc (later 50 parts per million)..	2 WP	15.3	34.8	45.7	15.2	4.4	......	......	......
1 part per million of boron and zinc (later 5 and 10 parts per million, respectively)......................	2 WP	16.3	21.4	39.8	21.4	12.3	5.1	......	......
2 parts per million of boron and zinc (later 10 and 50 parts per million, respectively)......................	2 WP	11.3	20.6	38.2	32.4	5.9	2.9	......	......
....	Ohio 4*	10.3	6.5	24.2	25.8	21.0	11.3	6.5	4.8
56 parts per million of ammonia added weekly.........	2 WP	10.7	9.4	10.9	35.9	14.1	17.2	9.4	4.7
Check plot....................	2 WP	12.0	6.9	29.2	27.8	23.6	8.3	4.2	......
1 part per million of copper (later 25 parts per million)..	2 WP	10.5	20.6	31.8	19.1	17.5	9.5	1.6	......
....	2 W	8.5	11.8	23.5	29.4	19.6	9.8	5.9	......

*For composition of the solution see tables 40 and 41.

Sources of nitrogen.—The source of nitrogen has been a controversial subject for many years. In our work, an attempt was made to determine the correlation between the plant growth during the winter months and the source of nitrogen supplied in the nutrient solutions. Tables 6, 7, 8, 9, 10, 11, and 12 show the various sources used and the effect of time intervals on the composition of the solutions. Nitrate tests during the months of November and December indicated an accumulation of nitrates in the solutions containing high ammonium which reached its peak from 15 to 18 days after the application of the solutions.

TABLE 6.—The parts per million analysis of the nutrient solutions using various nitrogen sources

	Solution				
	2 WP	Sodium nitrate	Ammonium sulfate	Ammonium nitrate	Calcium nitrate
Nitrates					
Potassium nitrate	495.5	....	....	....	....
Calcium nitrate	....	....	....	....	600.0
Ammonium nitrate	....	....	....	304.7	....
Sodium nitrate	....	600.1	....	....	....
Ammonia					
Ammonium sulfate	28.2	....	169.2	....	....
Ammonium nitrate	....	....	....	82.3	....
Calcium					
Calcium nitrate	....	....	....	....	193.3
Calcium sulfate	516.0	516.0	516.0	516.0	336.3
Monocalcium phosphate	84.0	84.0	84.0	84.0	84.0
Potassium					
Potassium chloride	187.1	496.3	496.3	496.3	496.3
Potassium nitrate	312.9	....	....	....	....
Phosphorus					
Monocalcium phosphate	400.0	400.0	400.0	400.0	400.0
Magnesium					
Magnesium sulfate	98.0	98.0	98.0	98.0	98.0

A comparison of the results of the use of ammonium sulfate and ammonium nitrate showed that the peak of nitrate accumulation was reached when all the ammonium disappeared from the solutions.

The growth of rose plants in the ammonium nitrate solution practically stopped when the pH reached 5.5 or lower. The same was true in the ammonium sulfate plot. The injury did not manifest itself upon the roots, but produced a yellowing of foliage, an almost complete drop of leaves, and subsequent failure of new axillary buds to develop. It may be assumed that the high hydrogen-ion concentration of the solution indirectly affected the nitrate reduction process and the ammonium accumulation.

TABLE 7.—The parts per million of nitrate nitrogen in the nitrogen source solutions at various intervals

Series 1

Nitrogen source	Days after preparation				
	3	7	11	18	23
Potassium nitrate and ammonium sulfate	550	500	372	250	150
Ammonium sulfate	56	135	185	220	150
Ammonium nitrate	275	340	372	435	310
Sodium nitrate	500	450	200	150	50
Calcium nitrate	500	425	372	210	100
Potassium nitrate and ammonium sulfate*	475	400	250	75	30

*Cinder medium.

TABLE 8.—The parts per million of nitrate nitrogen in the nitrogen source solutions at various intervals

Series 2

Nitrogen source	Days after preparation					
	1	4	6	8	13	18
Potassium nitrate and ammonium sulfate	470	375	350	325	175	150
Ammonium sulfate	5	50	95	130	185	175
Ammonium nitrate	290	340	435	420	465	450
Sodium nitrate	475	375	250	200	120	75
Calcium nitrate	475	350	225	130	100	70
Potassium nitrate and ammonium sulfate*	475	275	200	175	125	70

*Cinder medium.

TABLE 9.—The parts per million of ammonium nitrogen in the nitrogen source solutions at various intervals

Series 1

Nitrogen source	Parts per million of ammonium in fresh solution	Days after preparation				
		3	7	11	18	23
Potassium nitrate and ammonium sulfate	28	5	plus	0	0	0
Ammonium sulfate	170	100	45	10	plus	0
Ammonium nitrate	82	60	15	3	plus	0

TABLE 10.—The parts per million of ammonium nitrogen in the nitrogen source solutions at various intervals

Series 2

Nitrogen source	Parts per million of ammonium in fresh solution	Days after preparation					
		1	4	6	8	13	18
Potassium nitrate and ammonium sulfate	28	20	5	plus	0	0	0
Ammonium sulfate	170	130	100	40	20	5	plus
Ammonium nitrate	82	60	40	15	8	0	0

TABLE 11.—The effect of various sources of nitrogen on the prevailing pH at intervals after applications of new solutions

Series 1

Nitrogen source	Days after preparation				
	3	7	11	18	23
Potassium nitrate and ammonium sulfate	5.9	5.9	6.0	6.0	6.0
Ammonium sulfate	7.0	4.0	4.3	4.5	4.8
Ammonium nitrate	5.3	5.0	5.0	5.0	5.2
Sodium nitrate	6.0	6.3	6.6	7.0	7.3
Calcium nitrate	6.0	6.0	6.5	7.0	6.3
Potassium nitrate and ammonium sulfate*	5.5	5.5	5.6	5.8	5.8

*Cinder medium.

TABLE 12.—The effect of various sources of nitrogen on the prevailing pH at intervals after application of new solutions

Series 2

Nitrogen source	Days after preparation					
	1	4	6	8	13	18
Potassium nitrate and ammonium sulfate	6.4	5.9	6.1	6.1	6.1	6.1
Ammonium sulfate	6.2	5.4†	5.9	4.2	4.1†	5.5
Ammonium nitrate	6.3	6.2	5.7	5.7	5.6	5.7
Sodium nitrate	6.4	6.7	6.7	6.9	6.8	6.8
Calcium nitrate	6.6	6.5	6.6	6.6	6.7	6.6
Potassium nitrate and ammonium sulfate*	6.4	6.4	6.3	6.2	6.0	5.9

*Cinder medium.
†pH of the solution raised to 6.5 immediately after testing.

Magnesium sulfate additions (fig. 14 and 15).—It has been thought for some time that magnesium has a definite catalytic effect upon phosphorus in making it more available to plants. Our preliminary tests on roses indicated that additions of magnesium sulfate to the 2 WP solution at the rate of 200 grams to 100 gallons weekly showed a definite response in the spring in the development of adventitious shoots from the base of the plant known to the rose grower as "bottom breaks."

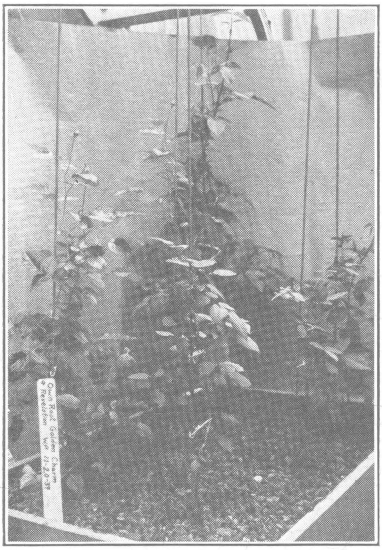


Fig. 14.—Growth of roses without additional magnesium sulfate. See figure 15.

Fig. 15.—The use of magnesium sulfate applied weekly at 10 grams per 5 gallons increases the growth of roses. Compare with figure 14.

Time of planting.—The usual procedure in commercial rose growing is to plant dormant-budded stock from January until April or May. Since the vitality of such stock is depleted in storage, a test was made to determine the comparative production between Happy Days roses planted in January and similar roses kept in storage at 40° F. and planted in March Table 13 shows a very significant difference in favor of the earlier planting.

TABLE 13.—A comparison of 1 year's production of Happy Days roses at 60° F. planted in January and March

Medium	Planting date	V-bottom bench			
		Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus
Silica gravel	March 22, 1939	10.4	2.3	14.4	83.3
FF Haydite	March 22, 1939	14.8	8.3	27.2	64.5
C Haydite	March 22, 1939	11.0	13.5	15.1	71.4
C Haydite	January 22, 1939	36.1	21.9	15.9	62.2

Planting with a ball of soil versus bare roots.—Grafted or "own-root" roses are grown on in pots before planting in soil. The same may be done with dormant-budded plants if they are to be held until late spring or summer planting. In gravel culture the original procedure was to wash the soil off such plants for fear of detrimental effects from inclusion of the soil in the inert media. Since the removal of the soil results in a definite check in initial growth due to the destruction of many of the root hairs, a series of tests was made to determine whether planting with a ball of soil was feasible. Table 14 indicates that such a procedure is not detrimental and that it may even result in higher production due to quicker starting of growth.

TABLE 14.—The effect of planting roses with and without a ball of soil on the production of two varieties

Variety	Treatment	Flowers per plant	Per cent by grade									
			Culls	Shorts	9 inches	12 inches	15 inches	18 inches	21 inches	24 inches	27 inches	30 inches plus
Mrs. F. D. Roosevelt	Soil ball intact...	21.0	4.8	3.2	19.8	26.2	18.3	14.3	7.1	3.9	1.6	0.8
	Soil ball removed.	16.5	9.1	9.1	18.2	32.3	21.2	9.1	1.0	......	......	......
Talisman	Soil ball intact...	10.8	.0	3.1	13.8	33.8	21.5	18.5	6.2	3.1	......	......
	Soil ball removed.	9.8	5.1	3.4	15.3	30.5	28.8	13.5	3.4	......	......	......

"Drying off" versus cutting back gradually.—The commercial rose grower rests his roses during the summer by the simple process of reducing the moisture at the roots for a week or two and then cutting the plants back, or he may reduce the moisture in the soil slightly and gradually cut his plants back stem by stem until a short, uniform height is obtained. In gravel culture, similar results can be obtained by withholding the solutions during the "drying" periods. After several different tests have been made, the results show that the following procedure is desirable: When the roses are ready for the rest period in the summer, the solution is withheld until the more succulent stems show signs of wilting, usually in about 3 days. At that time, the medium is flushed with clear water to bring about turgidity, and again the solution is withheld until wilting. A repetition of this drying will result in a rest period of 9 or 10 days. Then a ½ WP solution is applied until new root action develops. If gradual cutting back is desired, it can be done similarly to the process in soil by reducing the number of pumpings of the solutions. The results of these tests showed that production was similar with either method.

Red spider control.—To avoid the necessity of using spray materials, tests were made to determine the efficiency of the monthly inclusion of selenium in the solution as a toxic agent to mites. Tables 15, 16, and 17 indicate the results obtained. It will be noted that high concentrations of sodium selenate (Na_2SeO_4) provide up to 47 per cent control, which, however, is insufficient for practical purposes.

Pyrethrum, timbo, and derris were ineffective.

TABLE 15.—The control of red spider on Peter's Briarcliff roses with various insecticides applied monthly in nutrient solutions

Treatment	Date of infestation	Number counted	Per cent kill
Check	March 11, 1939 March 17, 1939	200 200	0.5 .0
0.025 per cent pyrethrum	March 11, 1939 March 17, 1939	200 200	3.0 1.0
0.025 per cent timbo	March 11, 1939 March 17, 1939	200 200	.0 1.5
0.025 per cent derris	March 11, 1939 March 17, 1939	200 200	.0 6.0

TABLE 16.—The control of red spider on Better Times roses by various concentrations of selenium in the nutrient solution

Date	Plot	Number counted	Per cent kill
January 6, 1939	Selenium 12.5 parts per million	133	13.5
	Selenium 10.0 parts per million	121	13.2
	Selenium 7.5 parts per million	240	7.1
	Selenium 5 0 parts per million	353	2.1
	Selenium 2.5 parts per million	321	.9
	No selenium	403	.0
January 18, 1939	Selenium 50 parts per million	200	32.0
	Selenium 35 parts per million	200	28.0
	Selenium 25 parts per million	200	20.5
	Selenium 20 parts per million	200	16.0
	Selenium 15 parts per million	200	11.5
	No selenium	200	1.5
January 23, 1939	Selenium 100 parts per million	200	15.5
	Selenium 75 parts per million	200	16.0
	Selenium 60 parts per million	200	17.5
	No selenium	200	2.0

TABLE 17.—The control of red spider on Peter's Briarcliff roses by weekly applications of selenium

Treatment	Number counted per leaf	Number killed	Per cent kill
Check	174 156	15 11	8.6 7.0
Initial selenium 25 parts per million; 2½ parts per million added weekly	144 109	41 32	28.0 29.0
Initial selenium 50 parts per million; 5 parts per million added weekly	87 74	41 35	47.2 47.1

TABLE 18.—A comparison of the production of roses at 60° F. in flat-bottomed and V-bottom benches containing soil and C grade Haydite

Planted January 22, 1939. Recorded to January 31, 1940

Variety	Type of plant	Soil, V-bottom bench				Haydite, V-bottom bench				Haydite, flat-bottomed bench				Soil, flat-bottomed bench			
		Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus
Better Times..	Own root	14.4	11.9	39.3	48.8	34.6	8.4	20.0	71.6	24.1	19.7	29.8	50.5	16.6	17.4	36.5	46.1
Better Times..	Started eye	17.7	9.9	26.2	63.9	32.6	10.2	13.4	76.4	22.6	9.5	28.1	62.4	17.1	13.0	31.4	55.6
Better Times..	Grafted	18.1	12.6	28.5	48.9	27.8	8.3	20.4	71.3	....	....	....	....	15.3	11.9	37.6	50.4
Happy Days..	Started eye	19.0	23.8	26.0	50.2	36.1	21.9	15.9	62.2	24.4	24.3	26.5	49.2	19.8	17.6	34.1	48.3
Joanna Hill ...	Started eye	18.3	13.9	35.3	50.8	35.1	2.3	14.4	83.3	25.3	5.5	24.4	70.1	18.6	13.3	38.6	48.1
Lucile Hill.....	Started eye	17.5	13.6	37.9	48.5	32.7	1.9	18.3	79.8	29.9	5.9	27.1	67.0	17.2	13.4	40.0	46.6
Peter's Briar-cliff..........	Started eye	15.7	20.0	33.9	46.1	29.7	20.6	16.7	62.7	25.0	25.9	28.8	45.3	17.7	17.2	33.2	49.6
Revelation.....	Dormant eye	16.0	20.3	35.9	43.8	20.2	16.8	22.0	61.2	....	....	....	....	....	....	....	....
Sunglow......	Dormant eye	22.4	21.0	33.7	45.3	36.9	12.2	28.0	59.8	....	....	....	....	....	....	....	....

TABLE 19.—A comparison of the production of roses at 56° F. in flat-bottomed and V-bottom benches containing soil, C grade Haydite, and coarse cinders

Planted January 27, 1939. Recorded to January 31, 1940

Variety	Type of plant	Soil, V-bottom bench				Haydite, V-bottom bench				Cinders, V-bottom bench				Soil, flat-bottomed bench			
		Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus
Talisman	Started eye	32.1	30.2	30.6	38.2	49.1	20.1	23.4	56.5	29.7	33.2	39.0	27.8	24.1	33.7	35.7	30.6
Yellow Gloria..	Started eye	25.2	28.4	39.0	32.6	40.6	16.9	34.5	48.6	33.7	15.2	30.8	54.0	25.5	25.8	39.3	34.9
Lestra Hibberd...	Started eye	20.5	49.4	37.1	14.5	27.1	38.0	39.4	22.5	37.2	24.8	27.4	47.8	20.9	44.4	11.9	43.7
Talisman	Rooted cutting	12.2	20.0	32.7	47.3	13.4	14.0	27.0	59.0	16.2	7.7	25.4	66.9	9.3	12.9	21.4	65.7

Rose production (fig. 16).—The usefulness of such a new process as growing roses in gravel depends upon a profitable production. Tables 18 and 19 show the results of 1 year's cropping of a number of different commercial varieties grown on a sufficiently large scale to be significant. It will be noted that gravel-grown roses produced larger quantities of salable flowers per plant and a greater percentage of longer grades than those grown in soil and treated in a typically commercial manner. Many times the differences were striking, yet the production in soil would equal that of the average grower.

Fig. 16.—Root systems of Better Times roses. Left to right—WP in cinders, WP in silica gravel, soil

Drainage in benches.—Tables 18 and 19 likewise show a very important point developed during these tests, one which was further substantiated by several other series of tests on a smaller scale. It was found that roses grown in flat-bottomed benches were not equal in growth and production to those grown in V-type benches. Careful examination disclosed that irregularities of the floor of the flat-bottomed bench made perfect drainage of the solution back into the tanks impossible. In the V-type bench, any standing solution remains under the half-tile in the center and does not come in contact with the roots. Emphasis of this feature resulted in greater perfection of growth in several commercial establishments where recommendations for the change were followed.

Temperature relations.—Many varieties of roses are usually grown at a night temperature of 58 to 60° F. It has often been suggested, however, that at lower temperatures, such varieties as Better Times, Peter's Briarcliff, Joanna Hill, and others would produce better quality but fewer flowers per plant. Since a difference of 3 to 5° F. means a considerable saving in fuel, tests were made to determine whether or not lower temperatures of the air combined with the warming of the solution would produce responses comparable to those obtained by growing such roses in the higher temperatures. Table 20 shows the results of growing the several varieties in 56° F. and 60° F. where the solutions in the lower house temperature were heated to 85° F. These solutions were, however, cooled to 70° F. by the media in the bench. It will be noted that except with own-root Better Times, no appreciable differences in production or quality were obtained.

TABLE 20.—A comparison of the production of roses in flat-bottomed benches containing C grade Haydite at 56° F. and 60° F.

Planted January 22, 1939. Recorded to January 31, 1940

Variety	Type of plant	60° F. house				56° F. house			
		Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus
Better Times......	Own root	24.1	19.7	29.8	50.5	31.1	15.0	41.3	43.7
Better Times......	Started eye	22.6	9.5	28.1	62.4	24.7	13.2	33.5	53.3
Happy Days.......	Started eye	24.4	24.3	26.5	49.2	25.1	23.0	31.3	45.7
Joanna Hill	Started eye	25.3	5.5	24.4	70.1	26.6	6.1	25.6	68.3
Lucile Hill.........	Started eye	29.9	5.9	27.1	67.0	24.6	5.3	29.5	65.2
Peter's Briarcliff..	Started eye	25.0	25.9	28.8	45.3	24.6	25.9	37.3	36.8

Zinc toxicity.—Symptoms of zinc toxicity were observed in roses whenever galvanized stakes used for support were inserted into the medium. Painting of these inserted ends with emulsified asphalt eliminated this difficulty.

CARNATIONS

Commercial method.—The growing of carnations in gravel presents comparatively few difficulties. The plants may be grown in the field and benched free of soil in July or August, or they may be handled in the greenhouse throughout their entire cycle of growth. With the latter method, rooted cuttings should be placed closely together in the bench in gravel and transplanted to their permanent places in May or June. The retention of a small soil ball is not objectionable.

TABLE 21.—Production of two carnation varieties in soil, cinders, and silica gravel

Planted in August and cropped till following May

Variety	Flowers per plant			Stem length, inches			Flower diameter, inches		
	Soil	Coarse cinders	Silica gravel	Soil	Coarse cinders	Silica gravel	Soil	Coarse cinders	Silica gravel
Mallow Pink...	11	12	14	20	22	20	3.0	3.0	3.0
Patrician......	9	12	13	18	20	18	3.0	3.2	3.2

Table 21 shows the results of one test indicating insignificant differences in production, stem length, and flower diameters between soil- and gravel-grown carnations. Greater stiffness of stem, however, may be expected in gravel-grown plants, provided that during the fall and winter months, pumpings are reduced to a minimum. The number of pumpings during that period will depend upon the light conditions. Very satisfactory results have been secured in cinders, Haydite, or gravel with pumpings made once in 2 or even 3 days.

When field plants are benched, they should be started on the WP solution and pumpings kept down to the minimum. As the plants develop more extensive root systems, the concentration should be raised to 2 WP. Table 22 shows a series of solution tests. The poorest results were obtained where the balance of nitrogen and potassium was apparently improper, notably in the New Jersey, Ohio 6, and Ohio 12 solutions.

Spread of stem rot will not occur as rapidly in gravel as in soil.

TABLE 22.—Production of carnations in C Haydite with various nutrient solutions

Nutrient solution	Puritan			Virginia			Chief Kokomo		
	Flowers per plant	Stem length, inches	Flower diameter, inches	Flowers per plant	Stem length, inches	Flower diameter, inches	Flowers per plant	Stem length, inches	Flower diameter, inches
2 WP	7.1	23.7	2.6	6.1	19.1	2.8	8.0	20.8	2.9
Ohio 6*	5.0	24.2	2.5	5.7	20.2	2.6	9.0	22.4	2.9
Ohio 10*	7.3	23.6	2.5	3.2	20.0	2.6	8.1	21.0	2.9
Ohio 11*	7.5	23.0	2.5	7.0	19.0	2.5	11.0	21.7	2.9
Ohio 12*	4.6	21.3	2.1	9.1	19.5	2.6	11.8	20.9	2.8
Ohio 13*	7.3	23.2	2.6	6.5	21.0	2.6	7.5	22.4	2.8
Ohio 15*	8.0	23.3	2.5	7.2	21.4	2.4	9.3	21.0	2.9
New Jersey	6.8	23.6	2.7	4.5	19.2	2.5	5.7	22.3	2.8

*For composition of the solutions see tables 40 and 41.

CHRYSANTHEMUMS

Commercial method.—Tests with chrysanthemums have been conducted for three seasons and show in general that little difficulty will be experienced in gravel culture provided drainage of the bench is perfect. Plants may be benched with a ball or planted directly out of the propagating bench. Washing off the soil ball is inadvisable. Table 23 gives the production of two varieties grown in silica gravel, limestone, and calcareous gravel with solution variations. The differences observed between solutions and between media were not significant. The application of a mulch of glass wool reduced the rapid drying out of the medium and gave significant differences in the production of Firebird. Figure 17 shows growth of Silver Sheen in various solutions. For best results use a finer medium than C grade Haydite.

TABLE 23.—Production of Firebird and Silver Sheen chrysanthemums in various media and nutrient solutions

Nutrient solution	Medium	Firebird	Silver Sheen	
		Ounces per plant	Stem length, inches	Flower diameter, inches
	Soil	3.7	39	4.5
WP	Silica gravel	4.2	42	5.5
2 WP	Silica gravel	4.0	40	5.0
2 WP*	Silica gravel	5.9	40	5.0
2 W	Silica gravel	4.2	38	5.0
2 D	Silica gravel	4.8	41	5.0
2 D	Limestone	4.3	37	5.0
2 D	Fine calcareous gravel	3.4	35	5.5
2 D	Coarse calcareous gravel	4.5	36	5.0

*Mulched with glass wool.

Fig. 17.—Silver Sheen chrysanthemums grown in soil (far left) compared with those grown in silica gravel with various solutions (remaining plants). Note the larger leaves developed in gravel.

SNAPDRAGONS

Removal of the soil ball.—The growing of snapdragons in gravel culture has been somewhat uncertain. In an effort to determine the most satisfactory commercial method of handling, three methods were employed. Seeds of the Christmas Cheer variety were germinated in sand; the seedlings were transplanted to small plots of silica gravel (fig. 18); and when the seedlings were of sufficient size, they were planted in the bench. Other seeds were germinated in soil, and the plants were placed in 2½-inch pots of soil until benching. The soil ball was removed by washing some of the plants; other plants were benched with the ball of soil. All plants were grown in a 2 WP solution in a V-bottom bench. The results of this test are shown in table 24.

Fig. 18.—Seedlings growing in a fine medium

The removal of the ball of soil decreased the number of stems produced by the plants. As a result of this decrease, slightly longer stems with somewhat longer spikes were produced, but these increases were insignificant.

TABLE 24.—The effect of the method of handling the young plants on the production of Christmas Cheer snapdragons

Media	Seedling media	Treatment	Stems per plant	Stem length, inches	Spike length, inches
C Haydite....................	Soil	Ball intact	5.6	32.8	5.7
C Haydite....................	Soil	Ball removed	4.6	34.1	6.1
C Haydite....................	Silica gravel	....	3.9	37.4	6.0
Silica gravel..................	Soil	Ball intact	9.1	31.8	5.6
Silica gravel..................	Soil	Ball removed	5.6	31.8	5.4
Silica gravel..................	Silica gravel	....	4.8	29.9	5.4
Coarse cinders.................	Soil	Ball intact	8.0	29.4	4.8
Coarse cinders.................	Soil	Ball removed	4.1	29.0	5.6
Coarse cinders.................	Silica gravel	....	3.9	31.4	5.8

Gravel-grown seedlings.—As a result of growing the seedlings in gravel, a reduction in the number of stems produced was observed. Slightly longer stems and spikes were produced, but the differences were insignificant. It is apparent that the most satisfactory commercial method is to grow the seedlings in soil in small pots and transfer them to the gravel bench with the ball of soil intact.

With the varieties White Wonder and Early Sunlight, such poor results were obtained from seedlings transplanted in gravel that it was necessary to discard the plants. Inferior growth was observed on these same varieties when the soil ball was removed in comparison with soil left intact.

Ammonium additions.—It has been thought that the presence of ammonium nitrogen in the nutrient solution has an inhibiting effect upon the growth of snapdragon plants. The WP solution (28 parts per million of ammonium) and the W solution (ammonium absent) were employed to determine the influence of ammonium nitrogen in the nutrient solution on growth and production. The results, shown in table 25, fail to show any inhibiting effect from the ammonium nitrogen.

TABLE 25.—The influence of ammonium nitrogen on the production of the Christmas Cheer snapdragon

Media	Solution	Stems per plant	Stem length, inches	Spike length, inches
C Haydite	WP (28 parts per million of ammonium)	8.3	25.0	6.3
C Haydite	W (ammonium absent)	8.1	23.5	5.2
Calcareous gravel	WP (28 parts per million of ammonium)	8.8	24.1	5.5
Calcareous gravel	W (ammonium absent)	8.2	24.1	5.3

The differences between the plants grown on the WP and W solutions were small. The WP solution produced less than one stem more per plant. The differences in stem and spike length were negligible. Although the plants with ammonium were a darker bluish-green during periods of cloudy weather in winter, this color faded to normal green as the intensity and duration of sunlight increased.

GARDENIAS

pH range.—The commercial culture of gardenias in soil necessitates the maintenance of an acid reaction (pH 5.0 to 6.0) for optimum growth and production. In our tests, various ranges of pH were used to determine the most satisfactory one with a WP solution. As indicated in table 26, the highest production occurred in the pH 7.0 to 7.5, and the lowest, at pH 4.0 to 5.5. Iron additions were made more frequently because of the rapid precipitation in the alkaline solution. Plants became chlorotic quickly but continued to grow and produce quality flowers. Despite the somewhat higher production in the pH 7.0 to 7.5, it was apparent that the maintenance of a 6.0 to 7.0 reaction would be most suitable for commercial gravel culture with additions of iron as needed (fig. 19 and 20).

TABLE 26.—Production of gardenias in C grade Haydite in a WP solution at varying pH ranges

pH	Flowers per plant	
	Veitchii	Belmont type
7.0–7.5	35.7	32.5
6.0–6.5	32.5	23.5
5.0–5.5	24.5	18.0
4.0–4.5	24.6	21.6

Fig. 19.—Root development in Belmont-type gardenias in various solutions. Left to right—2 D Purdue, 2 E Purdue, WP Ohio, and New Jersey. Note the large numbers of white roots on all except the New Jersey solution, which contained a high nitrogen level.

Fig. 20.—Root development on Belmont-type gardenias in various media with a WP solution. Left to right—silica gravel, calcareous gravel, C grade Haydite, and cinders. Poor root system on calcareous gravel due to an alkaline medium. Note the development of white roots on the other three media.

Media tests.—To determine the most desirable medium for the growth of gardenias in a WP solution, several types were used as shown in table 27.

TABLE 27.—Production of gardenias in various media with a WP solution

Medium	Flowers per plant	
	Veitchii	Belmont type
C Haydite	32.5	23.5
Silica gravel	27.6	18.6
Cinders	28.0	21.0
Calcareous gravel	11.0	11.5

The C grade Haydite proved superior, probably because of its aeration and moisture-holding capacity. Cinders disintegrated, and at the end of these tests, many of the large particles were reduced to the size of coarse sand. Calcareous gravel is alkaline and therefore unsuited for use.

Solution variations.—Several solutions were used in C Haydite and silica gravel on gardenias. The production is shown in table 28. The WP solution was superior to either the 2 D or 2 E with *Gardenia veitchii*, possibly because of the high nitrogen levels in relation to the low phosphorus in the Purdue solutions. Belmont types were not affected by the nutrient balance; their production was slightly higher with the 2 D solution. In silica gravel, the WP solution gave higher production on both *veitchii* and Belmont-type gardenias than the New Jersey solution. The latter solution has a very high nitrogen and phosphorus content in relation to the potassium.

TABLE 28.—Production of gardenias in C Haydite and silica gravel in various nutrient solutions

Nutrient solution	Medium	Flowers per plant	
		Veitchii	Belmont type
Ohio WP	C Haydite	32.5	23.5
Purdue 2 D*	C Haydite	12.2	27.0
Purdue 2 E*	C Haydite	13.6	23.0
Ohio WP	Silica gravel	27.6	18.6
New Jersey*	Silica gravel	21.6	13.0

*For composition of the solutions see tables 40 and 41.

LILIES

Commercial method.—Lilies respond satisfactorily to treatment in gravel. The usual procedure is the placement of the bulbs in the medium so that the tips are close to the surface. The starting solution should be WP, and the number of pumpings should be reduced to the minimum at the beginning.

TABLE 29.—Production of lilies in soil and various media in nutrient solutions

Date planted	Type	Medium	Salable flowers per stem	Blasted flowers per stem	Stem length, inches	Days to maturity
February 15...	Southern	Soil....................	4.0	0.5	24.0	109
	Southern	Silica gravel............	4.8	1.3	32.0	105
	Northern	Soil....................	2.8	.3	21.0	109
	Northern	Silica gravel............	3.0	.5	28.0	105
March 30.......	Southern	Soil....................	2.5	.0	20.0	84
	Southern	Silica gravel............	3.0	.3	20.5	84
	Northern	Soil....................	1.6	.0	17.0	84
	Northern	Silica gravel............	1.6	.0	17.5	84
April 18........	Southern	Soil....................	2.1	.1	20.0	75
	Southern	Silica gravel............	3.0	.2	27.5	75
	Southern	Cinders.................	3.2	.3	28.5	75
	Southern	Limestone..............	2.8	.1	28.5	75
May 16.........	Southern	Soil....................	2.0	.0	23.0	70
	Southern	Silica gravel............	2.3	.0	24.5	69

Table 29 shows the results of successive plantings of southern- and northern-grown *Lilium giganteum.* It will be noted that only insignificant differences appear between gravel- and soil-grown plants (fig. 21).

Fig. 21.—Lilies in silica gravel

Because planting lilies directly in the bench causes longer occupation of space than is profitable, a new scheme was tried and found successful. The bulbs were planted in shallow flats, watered with the WP solution, and then racked one on top of another in any cool place or under a bench. As soon as growth of the tops developed, the flats were plunged into benches filled with inert medium, and the benches were then flushed regularly. Table 30 shows the results of such treatment.

TABLE 30.—Lily production in gravel culture at 50° F.

Type		Flowers per stem	Stem length, inches	Number of days to mature
L. Giganteum	Benched December 6	5.1	33	150
L. Erabu	Benched January 12	5.8	32	101
L. Erabu	Flatted February 7 Benched February 28	4.9	33	93
L. Erabu	Flatted March 9 Benched March 29	3.5	32	97

In general, stronger stems and larger flowers can be expected from plants grown in gravel than from those developed in soil.

STOCKS

Comparison of soil and gravel.—Before it was discovered that complete drainage was necessary, many experiments were conducted to determine the comparative production of plants grown in gravel culture and in the commercial manner in soil. The results on stocks grown in a flat-bottomed bench in a WP solution are shown in table 31.

TABLE 31.—Production of Lilac Lavender stocks in soil, cinders, and silica gravel

Medium	Number cut		Stem length, inches	Spike length, inches
	Doubles	Singles		
Soil	36	60	16	4.5
Cinders	52	54	22	5.5
Silica gravel	51	54	19	6.0

In spite of the adverse conditions of poor drainage, longer stems and flower spikes were obtained in nutrient solutions than in soil.

Removal of the soil ball.—Several varieties of stocks were grown with a WP solution in a V-bottom bench containing silica gravel. Previously, the young plants had been grown in 2½-inch pots, and some were transplanted with the ball of soil removed by washing in water. On others, the soil ball remained intact and was set in the gravel so that one-half inch of gravel covered the surface of the ball of soil.

TABLE 32.—The effect on stem length of transplanting stocks with and without a ball of soil

Variety	Treatment	Number cut		Stem length, inches
		Singles	Doubles	
Gardenia	Soil ball intact	10	12	32.6
Gardenia	Soil ball removed	10	5	29.7
Rose Pink	Soil ball intact	21	26	31.3
Rose Pink	Soil ball removed	15	14	28.5
Lilac Lavender	Soil ball intact	20	32	32.0
Lilac Lavender	Soil ball removed	11	14	29.3

Transplanting with the ball of soil intact resulted in longer stems and normal color of the foliage. Leaves on plants transplanted with the soil ball removed assumed a gray-green color which remained until time of cutting. It is essential with all crops planted with a soil ball that the plants be well established. With several pumpings per day, the soil ball becomes soggy, and new roots develop into the medium surrounding the ball. If the plants are not well established in pots, the soil becomes poorly aerated from pumping of the nutrient solution, and death of roots and plant will result. When the crop is mature, the soil ball is readily removed by pulling the stem of the plant out of the medium, as the soil ball remains practically intact. In most crops, the roots that remain in the medium are insufficient to cause later complications.

SWEET PEAS

Commercial culture.—Of the various methods of germinating the seeds of sweet peas, none was more satisfactory for fall and winter sowing than planting the seeds in the row about 1 to 1½ inches deep directly in the medium in which they were to be grown. The medium was then flooded with a ½ WP solution and kept slightly on the dry side until the young plants appeared. Too dry a medium will result in death of plants from desiccation, and a wet medium promotes rot. Pumping is increased to two periods per day after the plants show signs of vigorous growth. Summer sowing of peas has been variable in results, and it is assumed that the medium becomes too dry and hot, so that the young plants wither quickly. A mulch of excelsior may overcome this difficulty. Manipulation of nutrition during cloudy winter weather is easily accomplished by varying the amounts of the different elements in the solution.

Comparison of soil and gravel.—Difficulties encountered in the commercial culture of sweet peas in soil are numerous. Production data compiled in table 33 show that there is an advantage in growing sweet peas in gravel. Increasing the concentration of the nutrient solution to the 3 WP level caused a drop in production and shortening of the stems. The highest production and best quality were obtained by the use of a 2 WP concentration.

TABLE 33.—The effect of growing sweet peas in calcareous gravel with various nutrient solutions

Nutrient solution	Stems per foot of row
Soil	144
WP	150
2 WP	178
3 WP	140
New Jersey (carnation)*	163
2 D*	158

*For composition of solutions see tables 40 and 41.

Media tests.—Since a neutral or slightly alkaline soil is desirable for the commercial culture of sweet peas, a test was made to determine the most suitable medium for growing peas in gravel culture. The acidity of the 2 WP solutions for each medium was adjusted twice weekly with sodium hydroxide to a pH of 7.0 to 7.5. Table 34 indicates that C grade Haydite is superior to other media used. The cinders used in these tests were alkaline, and the sweet peas produced heavily in this medium. Silica gravel, by nature of its composition, is very acid, and production was low in this medium. Calcareous gravel, although desirable because of its pH range, is not as well aerated as cinders or Haydite and is less desirable for that reason.

TABLE 34.—Production of sweet peas in a 2 WP solution with various media

Medium	Stems per foot of row
C Haydite	197
Silica gravel	83
Coarse cinders	190
Calcareous gravel	114

ASTERS

Comparison of soil and gravel.—A spring crop of asters was grown to determine the usefulness of gravel culture. As shown in table 35, the plants in the media subjected to the various treatments produced more flowers than the plants in soil plots. With the exception of the unlighted plot in Haydite, longer stems with larger flowers also resulted when plants were grown in the WP solution in a modified V-bottom bench.

TABLE 35.—Production of Giant Shell Pink asters in various media

Medium	Type	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	Soil ball intact	6.60	17.36	2.75
C Haydite*	Soil ball intact	6.60	8.00	2.20
C Haydite	Soil ball removed	6.75	17.93	2.90
C Haydite	Soil ball intact	7.78	19.44	3.10
Coarse cinders	Soil ball removed	7.05	18.15	3.11
Coarse cinders	Soil ball intact	7.02	19.94	3.15
Calcareous gravel	Soil ball removed	8.42	18.36	3.13
Calcareous gravel	Soil ball intact	7.45	19.67	3.19
Silica gravel	Soil ball removed	8.42	19.00	2.89
Silica gravel	Soil ball intact	7.86	18.40	2.89

*Unlighted after benching.

Removal of the soil ball.—The increases in production generally noted on plants set in the bench with a soil ball compared with those set after the ball had been removed by washing were not observed with asters. Table 35 shows little difference either in the method of handling or the type of medium used.

BOSTON YELLOW DAISY

Comparison of soil and gravel.—Differences in production between Boston yellow daisies grown with the WP solution in a V-bottom bench containing various media and those grown in commercial soil culture were marked.

TABLE 36.—Production of Boston yellow daisies in various media

Medium	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	52.1	9.6	2.1
Coarse cinders	61.8	13.9	2.3
Calcareous gravel	54.8	13.8	2.3
C Haydite	74.6	13.4	2.3

More flowers were produced on plants grown in nutrient solutions, though the differences in calcareous gravel were less, possibly because of the alkalinity of this medium. C grade Haydite proved best as a medium. Stem lengths were significantly greater in all media compared with soil, and flower diameters were one-fourth of an inch larger in all media. The differences in the size of the plants are illustrated in figure 22.

Fig. 22.—Comparative growth of Boston yellow daisy in soil (left) and gravel (right)

PANSY

Comparison of soil and gravel.—The production of Oregon Giant pansies in a flat-bottomed bench with a WP solution compared with normal soil culture is shown in table 37.

TABLE 37.—Production of Oregon Giant pansies in soil, cinders, and silica gravel

Medium	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	7.2	4.0	2.0
Cinders	8.9	5.5	2.4
Silica gravel	9.8	4.5	2.0

Although drainage conditions were poor, more flowers with longer stems were produced in gravel than in soil.

Removal of the soil ball.—With Don's Giant pansy, a test was made to determine the most practical commercial method of handling crops in nutrient solution culture. Since it had already been demonstrated many times that removing the ball of soil was detrimental, this phase was omitted. Seed was sown in sand; the seedlings were transplanted to small flats as shown in figure 18; and when of sufficient size, the seedlings were planted in the bench. Compared with this method, seed was sown in soil, and the seedlings were planted in 2½-inch pots. The resulting plants were set in the bench with the ball of soil as described previously. The results of this experiment are shown in table 38.

TABLE 38.—Production of Don's Giant pansy in C Haydite with a WP solution

Method of handling	Flowers per plant	Stem length, inches	Flower diameter, inches
Silica gravel	73.0	7.6	2.19
Ball of soil	111.1	7.5	2.14

The differences in stem length and flower diameter were insignificant, but a decided increase in favor of the soil ball method was noted in the number of flowers produced.

Under conditions of poor drainage, transplanting with a soil ball is not recommended, especially where large particles (three-fourths of an inch) are used as a medium, because the roots develop near the bottom of the bench when the upper portion of the medium dries. As a result, root and stem rots develop quickly, and the presence of a soggy ball of soil under these conditions is detrimental.

FEVERFEW

Comparison of soil and gravel.—A test similar to that with Boston yellow daisy was made with feverfew. In addition, feverfew was planted in C grade Haydite with a ball of soil to determine the effect of this planting method on production.

TABLE 39.—Production of feverfew in various media

Medium	Ounces of cut flowers per plant
Soil	11.8
Coarse cinders	12.6
Calcareous gravel	11.6
C Haydite	13.3
C Haydite, planted with a ball of soil	22.7

The differences in production were smaller than had been noted with other crops, and calcareous gravel was slightly inferior to soil. The greatest difference occurred where plants were placed in the bench with a ball of soil; the production of these plants was almost doubled.

ORCHIDS

It has long been an accepted practice among orchid growers to grow epiphytic forms on an organic material known as osmunda fiber, the roots of the cinnamon fern and its allies. To this, only water is applied. In some instances, manure water or liquid fertilizer in various forms has been used with varying degrees of success. Most of these trials have been total failures.

Although volumes have been written on the culture of orchids, very little scientific investigation has been done in relation to nutrition, photosynthesis, or respiration.

The work of Knudson (7) on the nonsymbiotic culture of orchid seedlings on an agar medium to which inorganic salts and sugar were added paved the way for further studies on nutrition.

The purpose of this investigation was to determine, if possible, the response of epiphytic orchids, namely those in the Cattleya tribe, in various stages of growth, to solution culture practices and to various types of media, both organic and inorganic.

Experiments were begun November 1, 1939, in which plants of all stages from seedlings to mature blooming size were used. The plots contained fine Haydite, silica gravel, and osmunda fiber. The solutions used were ½ WP, ¾ WP, and ½ Hoagland TC (tables 40 and 41).

Preliminary observations on small plants indicate that the additions of nutrient solutions were beneficial, particularly the ½ WP.

Most of the plants in osmunda fiber were better than those in Haydite and silica gravel. They exhibited less shrinking in the pseudobulbs and seemed to be firmer in texture. These plants were undisturbed at the beginning of the experiment, however, whereas those in silica gravel and Haydite had all fiber removed from the roots, and the shift caused a check in growth.

The response of mature plants to applications of solutions was not as striking as that of the younger plants. The mature plants received a severe check in replanting in the silica gravel and Haydite. Some varieties were definitely weak when planted. The outstanding observation was that varietal characteristics and individual plant vigor play an important part in the growth and development of plants regardless of the treatment applied. Some plants in all blocks appeared healthy and vigorous; others were definitely weak, chlorotic, and shrunken. The plants exhibiting weakness were in silica gravel and Haydite. There seemed to be no differential preference for any medium or chemical solution used.

Seedlings from the flask.—Usually seedlings are taken directly from the flask and planted in small "community pots" at the rate of about 25 to 50 per pot. The process is tedious and slow with many opportunities for failure. If seedlings could be planted in a sand medium and given solutions at intervals, the process might be hastened, and better seedlings produced.

In our tests, seedlings in sand receiving a chemical solution were better than those in osmunda fiber. The plants were larger and darker green in color. The seedlings responded equally well in the one-half concentration of both WP and TC solutions.

Pots that received weekly applications of vitamin B_1 solution in addition to the chemical solutions did not appear to be any different from those not treated.

MISCELLANEOUS CROPS

Euphorbia fulgens.—Plants out of 2½-inch pots, planted with a ball of soil, do exceptionally well in gravel culture if perfect drainage is provided. The 2 WP solution is best.

Calla lilies.—Satisfactory growth and good production result when calla lilies are grown in gravel. It is important that the tubers be free of root rot, since this disease is transmitted readily through the solution from plant to plant. The 2 WP solution is most suitable.

Bulbous and cormous plants.—Gladioli, bulbous iris, narcissi, hyacinths, freesia, ornithogalum, tulips, and many species of the genus *Lilium* were grown satisfactorily in the WP solution.

Fig. 23.—Wedgewood iris in C grade Haydite

Tuberous-rooted begonias.—Grown in gravel in a 2 WP solution, these plants produce large flowers in profusion on long stems.

Geraniums.—When grown for stock plants in gravel, geraniums produce large quantities of cuttings of exceptional quality.

Other plants that have been grown successfully in gravel culture since 1937 include calendula, bouvardia, buddleia, gerbera, marigold, candytuft, dahlia, annual chrysanthemums, salpiglossis, centaurea, and didiscus.

COMPARATIVE COSTS OF SOIL AND GRAVEL CULTURE

One of the drawbacks in engaging in the commercial practice of gravel culture is the apparent high cost of installation. The cost is not high, however, if the initial installation costs are prorated over a period of years. An examination of a concrete case will illustrate the point.

Fig. 24.—King Alfred narcissus in C grade Haydite

The difference in cost between the two benches is approximately $100. If the soil is removed yearly, the additional cost of removal and replacement would amount to about $20 per year, and with such management, the gravel and soil benches would equalize in cost in 5 years. If, however, the soil is steam-sterilized, it would take about 10 years to secure approximately equal costs. The upkeep of the gravel culture equipment during that period would be equalized by the savings resulting from the reduced cost of fertilizers and manures. On a 100-foot bench, such a saving should amount to about $5.00 per year. Thus, over a 10-year period, the costs of both benches would be practically equal

Cost of erection and filling of a 100-foot concrete flat-bottomed bench 4 feet wide	
100 feet of bench	$100.00
Soil and manure to fill bench	30.00
Labor	3.00
Total	$133.00

Cost of erection and filling of a V-type concrete bench 100 feet long and 4 feet wide	
100 feet of bench	$125.00
100 feet of half-tile	3.00
Pump	35.00
Pipe	3.00
Time clock	20.00
Emulsion	2.00
Medium	30.00
Labor	10.00
Total	$228.00

except for the saving in labor which would be in favor of the gravel culture method. With roses, the cost of labor per plant grown in soil is 30 cents, for each plant grown in gravel, only 15 cents. This saving, even were the production figures similar, would enable the grower to make a good profit even with the general low prices.

For growers having flat-bottomed benches 100 feet long and 4 feet wide, the cost of conversion to a modified V-bottom bench with 1-inch additions of concrete at the sides and a ½-inch addition in the center would be:

Seven bags of cement	$ 5.25
AAA Haydite or sand	2.00
Asphalt emulsion	2.00
Labor	6.00
Half-tile	3.00
Pipe	3.00
	21.25
Additional equipment of pump, clock, and medium	70.00
	$91.25

SUMMARY

Benches constructed for gravel culture should be perfectly waterproofed and built to make possible complete drainage of the solutions.

Tanks should be waterproofed and should be large enough to contain at least 40 per cent of the volume of the benches they serve.

Black pipe should be used in preference to galvanized to avoid toxicity from zinc.

Four-inch half-tile makes the most satisfactory trough for the bottom of the bench.

Sump pumps are easier to install than centrifugal and should be of sufficient capacity to provide rapid flow and quick return.

Haydite, trap rock, silica gravel, cinders, and calcareous gravel make suitable media for plants, although some difficulties may be experienced with cinders and calcareous gravel.

Of all solutions tried, the WP formula was found to be the most satisfactory for the majority of crops.

Solutions should be changed about once in 2 months, although with care, longer intervals may be acceptable.

Colorimetric microchemical tests should be made once a week for pH and phosphorus and once in 2 weeks for nitrates and potassium.

The maintenance of a pH of 6 to 6.5 will be found satisfactory for most crops.

The number of times a day to pump varies with the crop and the season. Four times a day is ample in the summer, and once a day in the winter. Some crops, like carnations, may need even less frequent applications of solutions.

To avoid the formation of algae on the surface of the medium, the solutions should be pumped to within 1 inch of the surface.

To avoid injury to the roots from spray materials, the benches should be flooded with clear water during spraying. After spraying, this water should be discarded and not allowed to drain back into the tanks.

Dormant-budded roses are best for gravel culture and should preferably be planted in January or February. The 2 WP solution has proved very satisfactory for roses, although additions of potassium to it during winter resulted in greater production. Additions of magnesium sulfate to the 2 WP solution in the spring have caused greater development of "bottom breaks" on roses. The use of ammonium nitrogen at a pH of 5 or below causes yellowing, defoliation, and check of axillary bud development on roses. Grafted or own-root roses can be planted with a ball of soil. Gravel-grown roses can be dried off somewhat similarly to those grown in soil. Frequent syringing of roses is safer in gravel than in soil, since there is no danger of creating too moist a medium. The base of galvanized stakes should be covered with asphalt before use, to avoid toxicity from zinc. Because of optimum conditions in gravel culture, greater production and better quality of roses result.

Stocks, snapdragons, feverfew, and pansies were more satisfactory if the ball of soil was retained when they were planted.

Stocks, snapdragons, pansies, feverfew, asters, Boston yellow daisies, sweet peas, and chrysanthemums in gravel culture produced higher quality and more flowers per plant than soil-grown plants.

Chrysanthemums should be benched either as cuttings directly from a propagating bench or else as potted plants. Perfect drainage is essential. Coarse media are not suitable.

Carnations require less frequent applications of solutions per day than many other crops.

Lilies and gardenias respond well to gravel culture.

The initial costs of equipment are higher for gravel culture than for soil. If its cost is prorated over a period of years, gravel culture is not any more expensive than soil culture, and because of labor savings and greater perfection of growth, it is actually more profitable.

APPENDIX

TABLE 40.—Composition of the various nutrient solutions

Nutrient solution formulas	Grams per 1,000 gallons of water	Per 1,000 gallons of water lb.	oz.	Millimolar concentration
Ohio WP				
Potassium nitrate, 13-0-44, KNO_3	2,630	5	13	6.9
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	439	0	15.5	.9
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2,043	4	8	2.2
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	1,090	2	6.5	1.4
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	4,856	10	12	7.5
Ohio W				
Potassium nitrate, 13-0-44, KNO_3	2,630	5	13	6.9
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2,043	4	8	2.2
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	1,090	2	6.5	1.1
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	4,856	10	12	7.5
Ohio 4				
Potassium nitrate, 13-0-44, KNO_3	3,940	8	11	10.3
Potassium chloride, 0-0-50, KCl	1,113	2	7	3.9
Ammonium nitrate, 35-0-0, NH_4NO_3	1,940	4	4.5	6.4
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	2,180	4	13	2.3
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9
Ohio 6				
Potassium nitrate, 13-0-44, KNO_3	2,630	5	13	6.9
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	439	0	15.5	.9
Potassium chloride, 0-0-50, KCl	2,225	4	15	7.9
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	2,180	4	13	2.3
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9
Ohio 8				
Potassium nitrate, 13-0-44, KNO_3	5,600	12	6	14.7
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2,100	4	10	2.3
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	1 400	3	1.5	1.5
Ohio 10				
Potassium nitrate, 13-0-44, KNO_3	5,260	11	10	13.8
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	878	1	15	1.8
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Sodium hexametaphosphate, 0-69-0, $(NaPO_3)_6$	4,020	8	14	10.4
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9
Calcium hydroxide, $Ca(OH)_2$	310	0	11	1.1
Ohio 11				
Potassium nitrate, 13-0-44, KNO_3	1,320	2	15	3.5
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	220	0	8	.4
Potassium chloride, 0-0-50, KCl	3,340	7	6	11.9
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	2,180	4	13	2.3
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9

TABLE 40.—Composition of the various nutrient solutions—continued

Nutrient solution formulas	Grams per 1,000 gallons of water	Per 1,000 gallons of water lb.	oz.	Millimolar concentration
Ohio 12				
Potassium nitrate, 13-0-44, KNO_3	2,630	5	13	6.9
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	439	0	15.5	.9
Potassium chloride, 0-0-50, KCl	6,675	14	12	23.7
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	2,180	4	13	2.3
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9
Ohio 13				
Potassium nitrate, 13-0-44, KNO_3	5,260	11	10	13.8
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	878	1	15	1.8
Potassium chloride, 0-0-50, KCl	4,450	9	13	15.8
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, $CaH_4(PO_4)_2 \cdot H_2O$	2,180	4	13	2.3
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9
Ohio 15				
Potassium nitrate, 13-0-44, KNO_3	5,260	11	10	13.8
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	878	1	15	1.8
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	4,086	9	0	4.4
Sodium hexametaphosphate, 0-69-0, $(NaPO_3)_6$	1,600	3	9	4.2
Calcium sulfate, $CaSO_4 \cdot 2H_2O$	9,712	21	7	14.9
Calcium hydroxide, $Ca(OH)_2$	310	0	11	1.1
Purdue 2D				
Magnesium sulfate, $MgSO_4$ (anhydrous)	246	0	9	.5
Treble superphosphate, 0-48-0, $Ca(H_2PO_4)_2 \cdot H_2O$	586	1	5	.6
Potassium nitrate, 13-0-44, KNO_3	4,158	9	3	10.9
Calcium sulfate (gypsum), $CaSO_4 \cdot 2H_2O$	2,873	6	5.5	4.4
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	529	1	3	1.1
Purdue 2E				
Magnesium sulfate, $MgSO_4$ (anhydrous)	246	0	9	.5
Treble superphosphate, 0-48-0, $Ca(H_2PO_4)_2 \cdot H_2O$	586	1	5	.6
Potassium nitrate, 13-0-44, KNO_3	2,495	5	8	6.5
Calcium nitrate, 15.5-0-0, $Ca(NO_3)_2 \cdot 4H_2O$	2,722	6	0	3.0
Ammonium nitrate, 35-0-0, NH_4NO_3	605	1	5.5	2.0
New Jersey (carnation)				
Ammonium sulfate, 20-0-0, $(NH_4)_2SO_4$	600	1	5	1.2
Monobasic potassium phosphate, KH_2PO_4	2,280	5	0.5	4.4
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	2,320	5	2	2.5
Calcium nitrate, 15-0-0, $Ca(NO_3)_2 \cdot 4H_2O$	7,000	15	7	7.8
Hoagland's TC				
Monoammonium phosphate, $NH_4H_2PO_4$	434.7	0	15.3	1.0
Potassium nitrate, KNO_3	2,293.2	5	1.0	6.1
Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$	3,568.5	7	13.5	4.0
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	1,863.5	4	1.8	2.0

TABLE 41.—Parts per million composition of some nutrient solution formulas

Based on complete solubility of all salts

Formula	Nitrate	Ammonium	Ammonium to nitrate	Total nitrogen as nitrate	Phosphorus	Phosphate	Potassium	Calcium	Magnesium
Ohio WP	400	28	100	500	65	200	250	310	51
Ohio W	400	....	....	400	65	200	250	310	51
Ohio 4	983	113	390	1,373	130	400	465	620	102
Ohio 6	400	28	100	500	130	400	500	620	102
Ohio 8	845	....	....	845	84	256	530	54	53
Ohio 10	800	56	200	1,000	322	987	500	580	102
Ohio 11	200	14	50	250	130	400	495	620	102
Ohio 12	400	28	100	500	130	400	990	620	102
Ohio 13	800	56	200	1,000	130	400	995	620	102
Ohio 15	800	56	200	1,000	128	392	500	580	102
Purdue 2 D	627	36	124	751	31	96	395	200	120
Purdue 2 E	835	35	120	955	31	96	237	200	120
New Jersey (carnation)	875	40	140	1,015	130	408	170	283	58
Hoagland's TC	868	18	62	930	31	95	235	160	486

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